Coal Combustion Control Technologies

The SAB recognizes the challenges encountered by industry and DEQ to identify applicable control strategies for mercury and other pollutants from burning coal. To assist both government and industry with difficult control strategy decisions, this task force prepared a summary table of traditional and alternative control devices which are available for combustion sources. Included are notes about the applicability of the technology for other processes, typical control costs, and typical efficiencies that can be achieved. In addition to the control technology summary charts, the task force sought to address the specific interest and controversy surrounding mercury emissions from combustion sources. Mercury remains one of the most difficult pollutants to measure and control, so we have developed a summary report outlining the concerns with mercury exposure, sources of mercury emissions, and possibilities for controlling those emissions.

The report consists of three parts. The written document contains a discussion of the health effects of mercury, along with information about anticipated regulations regarding mercury control. It is followed by a table comparing emissions from state-of-the-art coal burning units with the emissions levels that can be achieved in natural gas combustion plants, recognizing that both fuel sources are vital to overall electrical utility generation in the US. The third part is the table which summarizes available control technologies for a variety of pollutants, including mercury.

Part I. Mercury Background Information and Anticipated Regulations[1]

Background

Concerns about the potential impact of mercury (Hg) on public health and the environment have led to increased pressure to adopt new regulations and identify potential methods of controlling industrial emissions of mercury. Nationally, EPA estimates that coal-fired electric power plants account for 40 percent of U.S. manmade mercury emissions.[2] Industrial boilers account for10 percent, hazardous waste incinerators 5 percent, and chlorine production about 5 percent. Municipal and medical waste incinerators each account for less than 5 percent, down from much higher levels in the past before MACT standards were implemented. Other industrial processes, such as scrap steel recycling, can be locally and regionally significant mercury emission sources.[3]

The concerns about health effects of mercury arise because mercury is a neurotoxin that in certain forms can cause abnormal brain development in fetuses and mental retardation and learning disabilities in children. EPA estimates that one to three percent of American women of childbearing age eat enough mercury-containing fish to be at risk.[4] However other studies suggest that eight percent of such women may have mercury levels that could harm a fetus.[5] Fish tissue studies have prompted consumption advisories and restrictions for certain species caught in segments of Virginia's and other states' waterways.[6] Also, the Food and Drug Administration and EPA have issued advice on consumption of marine fish due to mercury. Past EPA actions have led to reductions in air and water releases of mercury from a number of industries. Pollution prevention approaches are helping reduce the presence of mercury in many products. Currently a number of states and the EPA propose to regulate mercury emissions from coal-fired power plants, which are the largest anthropogenic sources of mercury emissions.[7, 8]

Mercury Routes and Sources

In some waterways mercury contamination can be ascribed to surface releases from specific industrial plants and contaminated lands. In other cases smaller sources, such as dental practices, may collectively, via municipal wastewater treatment plants, be major contributors of a watershed's mercury load. However, there are waterways where air deposition appears to be the primary route of mercury contamination. The relative contributions of local air emissions of mercury to surface deposition as compared to regional, national, and global long-range transport are not well understood.

Relatively stagnant and acidic "blackwaters," such as in Southeastern Virginia, Eastern North Carolina, and the Florida Everglades appear to be particularly vulnerable to the reactions that create methylmercury, an organic compound that bioaccumulates in fish, wildlife, and human beings.[9]

A national mercury deposition network (MDN) has measured wet (rain and snow) but not dry deposition of mercury.[10] There are no MDN sites in Virginia but two sites in Eastern North Carolina are illustrative. North Carolina notes a modest correlation between reducing nearby mercury emissions and reduced deposition. However, the state correlates its relatively high emissions with high ambient air mercury levels, high wet air deposition amounts, and high levels in selected fish species and the people who eat those fish.

Florida has seen a more dramatic correlation between local emissions and fish and wildlife mercury levels.[11] The state estimates that 98 percent of mercury contamination in the Everglades is from air deposition and that over half of that mercury is emitted locally. Florida DEP concludes that reductions in local air emissions of mercury resulted in a 60 percent decline in Everglades' fish and wildlife mercury levels over a 15-year period since peak mercury emissions. The emissions reductions were primarily accomplished through a shutdown of a waste incinerator and measures taken at other waste-to-energy plants to prevent combustion of mercury-containing wastes and control emissions.

Virginia Sources of Mercury Air Emissions[12]

The Toxic Release Inventory, which covers manufacturing and utilities, reports 1.09 tons of mercury compounds released to the air in Virginia in 2002, of which 0.643 tons came from electric utilities. The Environmental Working Group, an environmental advocacy organization, used EPA and Department of Energy data to estimate 0.688 tons emitted by nine power stations in 1998. EPA's Electric Utility Mercury Software Tool estimates 0.63 tons of mercury emissions from 36 Virginia electrical generating units (EGUs) in 1999. While these estimates vary somewhat, they all suggest roughly two-thirds of a ton emitted annually by Virginia electric utilities. However, a variety of industrial sources, including coke ovens, secondary steel processors, waste incinerators, and non-utility coal combustion also contribute to mercury air emissions.

Mercury Controls[13]

Particulate matter (PM) and sulfur dioxide (SO_2) controls can achieve significant mercury reduction as a co-benefit. The following table adapted from presentations at a North Carolina Division of Air Quality workshop illustrates such reductions:

Controls	Bituminous (% Hg removal)	Duke Energy expectations for conformance with the NC Clean Smokestacks Act (% Hg removal from bituminous)	Subbituminous (% Hg removal)
PM Only			
Cold side electrostatic precipitator (CS-ESP)	46	25 to 35	16
Hot side electrostatic precipitator (HS-ESP)	12	0 to 9	13
Fabric Filter (FF)	83		72
PM scrubber	14		0
Dry Flue Gas Desulfurization (FGD)			
Spray Dryer Adsorber (SDA) + ESP			38
SDA + FF	98		25
Wet FGD			
CS-ESP + Wet FGD	81	80 to 90 (with SCR) 55 to 65 (w/o SCR)	35
HS-ESP + Wet FGD	55		33
FF + Wet FGD	96		

SCR: selective catalytic reduction of NOx. FF: fabric filter can also be referred to as baghouse.

Mercury removal varies considerably depending on the type and source of coal as well as combustion and post-combustion conditions. Virginia electric utilities burn bituminous coal but bituminous coals also vary in composition. Oxidized or reactive compounds of mercury as well as particulate-bound mercury are more easily scrubbed by wet flue-gas desulfurization (FGD) than elemental mercury. SCR for nitrogen oxides (NOx) control helps convert elemental mercury to HgCl, which is more easily scrubbed by FGD, but at a possible cost of increasing corrosivity of flue gases. Some low-NOx burners leave some carbon in fly ash, which enhances mercury removal.

According to EPA's Electric Utility Mercury Software Tool, Virginia EGUs that employ both FGD (or fluidized bed combustion in one case) and fabric filter are estimated to achieve 92 to 99 percent mercury control.[14] EGUs with CS-ESP and no FGD get 29 percent and those with HS-ESP and no FGD achieve just 11 percent.

Specific mercury abatement measures are also being developed. The most mature of these is injection of activated carbon into flue gas. Some low NOx burners also produce a larger proportion of carbon in the fly ash which provides a mercury adsorption mechanism. Some consider activated carbon injection to be commercially available now since eight long-term full-scale tests have been performed, with another dozen under way or close at hand. Carbon adsorbs mercury, including the elemental form. Based on commercial scale tests, activated carbon injection combined with CS-ESP or fabric filter can yield over 70 percent mercury removal efficiency even in the absence of FGD.

It has been estimated that to retrofit a 250 megawatt (MW) plant that has a CS-ESP and operates at 80 percent capacity with an activated carbon system designed for 70 percent mercury removal would cost $790,000 for the carbon injection system plus annual carbon costs of $2.56 million. If retrofitted with a fabric filter, capital costs would include $12.5 million for the fabric filter plus $790,000 for the injection system. However only $769,000 of carbon would be consumed annually. So there is a tradeoff between capital and operating costs in opting between ESP and fabric filter. It should be noted that these costs are a function of plant size, not the amount of mercury removed. Also, these costs may vary depending on specific conditions at specific plants.

A disadvantage of activated carbon injection or leaving carbon in fly ash is that the resulting fly ash may be unsuitable for cement production. The EPRI-developed TOXECON system solves this problem by incorporating two PM controls. An ESP collects over 90 percent of fly ash, which is then available for cement manufacture. Then carbon is injected into the remaining exhaust, followed by particulate and thus mercury removal by a fabric filter.

A number of other sorbents, additives, pre-combustion coal cleaning approaches, catalysts, electron beam, and low temperature plasma approaches are being developed and tested to control mercury specifically or as part of multipollutant controls. While some have been tested on a utility-scale and some are claimed to offer cost advantages over a conventional ensemble of PM control-FGD-SCR, none have been applied widely enough to be considered commercially proven.

For new coal-fired plants, integrated gasification combined cycle (IGCC) may be an option. IGCC can achieve very low emissions for all regulated pollutants. For mercury control, running a relatively small volume of synthesis gas over a carbon bed is easier than treating very large volumes of flue gas. This approach is used to remove mercury at a number of mercury-rich natural gas deposits. New gasification technologies operate at high temperatures to avoid hazardous organic wastes associated with earlier synthesis gas and town gas production. Because of the potential for lower emissions, IGCC technology may form the basis of tighter BACT limits.

Whether collected as PM, scrubber sludge, or in other form the mercury has to go somewhere. Care should be taken to assure that air emissions controls do not simply transfer the mercury problem to another medium through another route. Decreased mercury use in commerce suggests limited opportunities to recover mercury for recycling. Life-cycle and industrial ecology approaches may be useful for understanding best mercury management options.[15]

Conclusions

Both short- and long-range transport and deposition may contribute to locally high levels of mercury in fish tissue. Data from Florida and North Carolina correlate reduced local mercury emissions due to modifications and shutdowns of waste incinerators with lower quantities of mercury deposited and found in fish and wildlife. However, the correlations vary in strength, and apply almost exclusively to waste incineration sources.

Conventional PM and SO_2 control technologies yield mercury control as a co-benefit. SCR may also assist in removal efficiencies. A combination of FGD (wet or SDA) plus fabric filter can remove over 80 and even high 90s percent of mercury when bituminous coal is burned, because there is a lower percentage of elemental mercury. Fabric filtration alone may remove the majority of mercury from bituminous coal derived flue gas. CS-ESP alone may remove a quarter or more while HS-ESP removes little. Removal efficiencies are affected by coal quality and combustion and post-combustion conditions.

Activated carbon injection is the most mature mercury-focused pollution control technique. A system exists to counter the problem of carbon-rich fly ash being unsuitable for cement production. A variety of other technologies that are focused on mercury control alone or are part of a multipollutant control ensemble offer significant promise but are generally not considered to be commercially proven by many industrial and utility sources.

Mercury management strategies must consider the form, mobility, and fate of mercury recovered by pollution controls. It is important to avoid creating other mercury-related environmental and health risks as a by-product of coal combustion pollution control.

Controlling Mercury Under SO_2 and NO_x Regulations

EPA published several alternatives to regulate mercury emissions from coal-fired utility EGUs in January 2004. These alternatives have been presented in three proposed rules – the Utilities Mercury Reductions Rule (modified by the Supplemental Mercury Proposal in February, 2004), and the Interstate Air Quality Rule. However, reaction has been strong to the proposals and EPA has acknowledged that its projections for mercury reductions may have been too optimistic. EPA recently announced that it was reconsidering the basic proposal data because of opposition by state environmental agencies and major health and environmental organizations.

The Utility Mercury Reductions Rule (including the Supplemental Mercury Proposal)

The Utility Mercury Reductions Rule contains three alternatives for controlling mercury emissions from power plants:

1. Under authority of the Clean Air Act (CAA) Section 111, the first option would establish standards of performance to limit the emissions of mercury from existing and new utilities. The program would be structured in the same manner as the Acid Rain Trading program. Each participating state would be assigned “allowances” of mercury emissions that can then be allocated to utilities. The allowances can be traded among plants, so that one facility that “over-controls” mercury emissions can sell allowances to another facility that does not achieve the same level of mercury reduction. Each utility plant would be required to maintain adequate allowances to cover the mercury emissions each year.

   For states that choose not to participate in the trading program, mercury allocations will become fixed, unit-level emission limitations. EPA implies that federal assistance will be limited for states that reject this cap-and-trade approach. The number of tons of mercury allowances that would be allocated to each state are listed in the EPA proposal.

This alternative would also extend the reach of 40 CFR 60 Subpart Da (New Source Performance Standards [NSPS] for utility boilers) to any fossil fuel fired combustion unit serving a generator of more than 25 MW that produces electricity for sale.

The proposed standards for mercury for new coal-fired Subpart Da units are subcategorized based on the type of coal being burnt. The limits are output based as follows:

- Bituminous units: 0.0060 lbs. per gigawatt hour (GWh) gross electrical output
- Sub bituminous units: 0.020 lbs. per GWh gross
- Lignite units: 0.062 lbs. per GWh gross
- Waste coal units: 0.0011 lbs. per GWh gross
- Integrated gasification combined cycle units: 0.020 lb per GWh gross[16]

EPA released a supplemental proposal on February 24, 2004 providing rule language for this cap-and-trade approach. Each state would be required to impose control measures to demonstrate how statewide mercury emissions will be limited. States would assign a mercury emissions level (cap) to each coal-fired power plant to meet statewide emissions budgets. In addition, states could meet their budgets by allowing the plants to buy and sell allowances nationally.

2. The second alternative presented in the Utility Mercury Reductions Rule would control mercury emissions by establishing Maximum Achievable Control Technology (MACT) limits for utility boilers. This proposal is based on EPA's finding that mercury should be regulated as a hazardous air pollutant (HAP). A MACT rule regulating mercury would be developed based on the requirements of CAA Section 112(d).

   Under the conventional Section 112(d) MACT, the standard for new coal-fired EGUs of greater than 25 MW is as indicated above. Existing sources would be subject to somewhat less stringent MACT standards as follows:

   - Bituminous units: 0.021 lbs. per gigawatt hour (GWh) gross electrical output or 2.0 lbs. per trillion Btu (TBtu) heat input
   - Sub bituminous units: 0.061 lbs. per GWhr gross or 5.8 lbs. per TBtu input
   - Lignite units: 0.098 lbs. per GWh gross or 9.2 lbs. per TBtu input
   - Waste coal units: 0.0041 lbs. per GWhr gross or 0.38 lbs. per TBtu input
   - Integrated gasification combined cycle units: 0.2 lbs. per GWh gross or 19 lbs. per TBtu input[17]

3. EPA has also accepted comment on an alternative cap-and-trade program, which would be a national program developed under Section 112 (n). This approach would have advantage of allowing EPA to directly implement a national trading program under Section 112, instead of relying on the states to participate in a mercury trading program as discussed in item 1. Other requirements would be similar to the trading program discussed above.

A cap-and-trade approach would clearly benefit industry, in that each facility would be able to choose whether to install additional controls or purchase credits. Under conventional MACT requirements, each affected facility is required to meet the applicable emission limit in a short time frame. EPA argues in favor of the cap-and-trade program because they believe that greater reductions are possible with cap-and-trade. Once industry achieves the MACT standard, there is no incentive to reduce mercury further. In addition, MACT controls must be based on existing technologies. Thus, EPA believes that the motivation to develop new and innovative solutions would be inhibited by the time pressure to comply in only three or four years. This would not be the case under the extended deadline proposed under Section 111.

A potential drawback with this approach is that mercury controls would not be based on the recognition of mercury as a hazardous air pollutant. Environmental advocates and some states argue that the proposed mercury limits based only on co-benefits from SO2 and NOx controls do not adequately control mercury as would a traditional MACT standard. A traditional MACT standard would typically cover other HAP emissions, as well. Opponents are also concerned that cap-and-trade programs allow some utilities to continue to emit pollutants at high levels, creating toxic "hot spots" that put certain populations at risk. The more conventional maximum achievable control technology (MACT) approach removes this concern.

The Interstate Air Quality Rule

The Interstate Air Quality Rule was published on the same day as the Utility Mercury Reductions Rule. In it, EPA seeks to reduce emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from 29 states in the eastern US. While not specifically requiring mercury reductions, significant reductions of mercury are anticipated as a co-benefit of installing additional SO_2 and NO_x controls.

Clear Skies Legislation

In addition to regulatory proposals from EPA, Congress has been considering legislation that would set national caps on NO_x, SO_2, and mercury. This legislation would provide state programs with the authority to set source-specific emissions limits for sources within their borders to ensure that ambient air quality standards are met. Like the other cap-and-trade programs, the legislation would provide flexibility for facilities to control emissions or buy credits. The NOx and SO2 requirements affect all fossil fuel-fired electric generators greater than 25 megawatts (MW) that sell electricity. Mercury requirements affect only the subset of these units that are coal-fired.

According to EPA, the advantage of a program which requires mercury in the same manner as SO_2 and NO_x is that significant mercury emissions reductions would be achieved as a co-benefit of the air pollution controls designed and installed to reduce SO_2 and NO_x. Thus, the coordinated regulation of Hg, SO_2, and NO_x allows Hg reductions to be achieved in a cost effective manner.

Conclusions

There are several regulatory and legislative actions underway to regulate mercury emissions. Even though emission reductions may ultimately be similar, concern has been expressed over regulating mercury as a conventional pollutant rather than a HAP because of the time to compliance. EPA's proposal to regulate mercury in conjunction with SO_2 and NO_x would extend the time of compliance, and reductions, out to 2018. MACT compliance for HAPs is generally required 3 years after the rule is final, meaning utilities would need to control mercury emissions as early as 2007 under MACT.

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[1] The majority of information in this report, except for the discussion of regulatory proposals, is adapted from a document entitled, "Fact Sheet on Power Plant Emissions of Mercury in Virginia", dated July 13, 2004, and written by Rodney Sobin, Office of Air Permit Programs, Virginia DEQ.

[2] U.S. EPA "Frequent Questions" fact sheet on mercury at http://www.epa.gov/mercury/information1.html

[3] For example, the Virginia Toxic Release Inventory (TRI) for 2002 shows a Chaparral Steel facility as having emitted 0.145 tons of mercury, which is 13.3% of mercury air emissions from all TRI reporting manufacturing and utility facilities in Virginia. This amount is much greater than that emitted annually by any single electrical generating unity in Virginia and greater than all but one electrical generating station (four units constituting the Chesterfield Power Station).

[4] Cited in "POWERful Facts About Mercury in North Carolina," Center for Energy and Economic Development (undated, no other publication information, distributed at the NC Division of Air Quality, *Mercury and Carbon Dioxide Workshop*, Raleigh, NC, April 19-21, 2004.

5 Cited in "Who'll Stop the Mercury Rain?" U.S. News & World Report, April 5, 2004.
6 Virginia mercury-related fish consumption restrictions and advisories are in place for Lake Gordonsville (also known as Bowlers Mill Lake); Lake Trashmore; Lake Whitehurst; and segments of the Pamunkey River; the Mattaponi River; Herring Creek; the North Fork of the Holston River; the South, South Fork Shenandoah, and Shenandoah Rivers; Blackwater River; Great Dismal Swamp Canal; and Dragon Run Swamp. The latter three are "blackwater" areas and their mercury contamination has not so far been associated with any obvious surface sources. *Richmond Time –Dispatch*, October 1, 2004 and Alex Barron (Virginia DEQ) and materials distributed at the Virginia DEQ water program Mercury Advisory Committee meeting held April 16, 2004.
7 EPA has offered three proposed approaches including a MACT, a modified MACT with a tradable allowance component, and a cap-and-trade program under Clean Air Act Section 111 authority. These are still in the comment stage and have engendered controversy. William Maxwell (EPA) at the *Mercury and Carbon Dioxide Workshop*.
8 CT has a rule and WI, MA, and NJ are developing rules regulating EGU mercury emissions. NH and NC will develop recommendations to the legislature for mercury controls in 2004 and 2005, respectively, under the NH Clean Power Act and NC Clean Smokestacks Act. Several other states, including VA (Del. Reid's bill in late 2003), have proposed bills or assembled task forces to examine and address mercury emissions. Martha Keating (Clean Air Task Force) at the *Mercury and Carbon Dioxide Workshop*.
9 Conclusions from Virginia DEQ water program Mercury Advisory Committee meeting held April 16, 2004 and presentations by Michelle Woolfork (NC Division of Water Quality) and by Thomas Atkeson (FL DEP), Robert Steven (FL DEP), and Matthew Landis (U.S. EPA) at the *Mercury and Carbon Dioxide Workshop*.
10 Steve Schliesser and Todd Crawford (NC Division of Air Quality) at the *Mercury and Carbon Dioxide Workshop.*
11 Thomas Atkeson (FL DEP), Robert Steven (FL DEP), and Matthew Landis (U.S. EPA) at the *Mercury and Carbon Dioxide Workshop.*
12 DEQ TRI report for 2002; Environmental Working Group at http://www.ewg.org/reports_content/mercuryfalling/Virginia.pdf ; EPA's Electric Utility Mercury Software Tool available for download at http://www.epa.gov/ttn/atw/combust/utiltox/utoxpg.html
13 This section is based largely on Michael Durham (ADA Environmental Solutions) "Performance and Costs of Mercury Controls for Bituminous Coals" at the *Mercury and Carbon Dioxide Workshop* except for the Duke Energy mercury control expectations, which are from Robert McMurry (Duke Power) and information on IGCC, which is from Joe Chaisson (Clean Air Task Force), both at the *Mercury and Carbon Dioxide Workshop*. Virginia EGU information is from EPA's Electric Utility Mercury Software Tool, previously cited.
14 Examples are AES Warrior Run, Clover Power Station, Virginia Power- Hopewell (currently out of service), Mecklenburg Cogeneration, and SEI-Birchwood which achieve over 90 percent Hg removal.
15 The case of scrap steel recycling, including the Chaparral Steel facility previously cited, is illustrative. In that industry mercury emissions are due to mercury contained in scrap, such as mercury-containing switches in scrapped automobiles. The solution to this problem is for automobile manufacturers to avoid using mercury-containing components. A number of automobile makers have phased out such switches. While this solution is not applicable to mercury from EGUs, the point is the need to look broadly at the source, form, and fate of pollutants and to consider options beyond end-of-pipe pollution controls.
16 The proposed MACT for new sources would allow IGCC higher mercury emissions than for bituminous coal combustion units even though, as discussed earlier in this report, mercury emissions are likely to be more easily and cost-effectively controlled through pre-combustion treatment of IGCC synthesis gas that treatment of flue-gases post combustion in coal-fired units.
17 The proposed MACT for existing units would allow much greater mercury emissions from IGCC plants than from other coal fueled EGUs even though, as discussed in the previous endnote and in this report, mercury removal from IGCC synthesis gas is easier and more cost-effective than mercury controls on flue gas.